

NASA UAS Traffic Management National Campaign

Operations across Six UAS Test Sites

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Abstract—NASA’s Unmanned Aircraft Systems Traffic Management research aims to develop policies, procedures, requirements, and other artifacts to inform the implementation of a future system that enables small drones to access the low altitude airspace. In this endeavor, NASA conducted a geographically diverse flight test in conjunction with the FAA’s six unmanned aircraft systems Test Sites. A control center at NASA Ames Research Center autonomously managed the airspace for all participants in eight states as they flew operations (both real and simulated). The system allowed for common situational awareness across all stakeholders, kept traffic procedurally separated, offered messages to inform the participants of activity relevant to their operations. Over the 3-hour test, 102 flight operations connected to the central research platform with 17 different vehicle types and 8 distinct software client implementations while seamlessly interacting with simulated traffic.

Keywords—UAS; UTM; air traffic management

I. INTRODUCTION

Operators of unmanned aircraft systems (UAS) are increasingly requesting access to the National Airspace System (NAS). As an illustration, by January of 2015 there were fewer than ten Section 333 exemptions (authorizations to perform commercial small UAS operations prior to future rule making) issued by the FAA and in December of the same year, that number was over 300 [1]. The current system of exemption applications for particular vehicles, operations, and areas is not scalable for the vast number of use cases anticipated by government and industry in the near future. Therefore, a system for managing this traffic and maintaining awareness of operations will likely be required. NASA is researching concepts related to these technology and policy gaps under an effort called UAS Traffic Management (UTM), originally proposed in 2014 [2]. The major objective of this work is to determine how to enable access to the low altitude airspace for small UAS safely, efficiently, and fairly.

There are two over-arching philosophies and five basic operations principles in the development of the UTM research platform and overall concept. The first philosophy is “flexibility whenever possible, structure when necessary” and the second is “risk-based airspace requirements.” The principles are:

- 1) *All UAS, operators, and communications are authenticated before use of the airspace.*
- 2) *UAS will avoid each other and other objects.*

- 3) *UAS will stay separated from manned aviation.*

- 4) *All of the constraints, including dynamic constraints for public safety operations, are available to all stakeholders for common situational awareness.*

- 5) *Access will be fair and efficient.*

More detail on the overall concept for UTM is provided in the UTM concept of operations paper [3].

NASA’s effort is staged in four parts called Technical Capability Levels (TCL). Each TCL is defined by the risks associated with operations, with increasing risks as the TCL increases. TCL 1 is focused on visual line-of-sight (VLOS) operations in rural locations where the interaction of those operations with other UAS, manned aviation, structures, and people are low. This operational paradigm enables several known use cases including, but not limited to, infrastructure monitoring and inspection, agriculture, firefighting, and film/videography. The higher-level TCLs can be briefly summarized as follows (note that these are not complete descriptions of the objectives): TCL 2 introduces beyond visual-line-of-sight (BVLOS) operations, TCL 3 allows for operations in populated areas, and TCL 4 enables urban operations and handles large-scale contingency management.

Given the development philosophy and the operational environment for TCL 1, NASA has developed a research platform to begin testing concepts for UTM. Briefly, the architecture of the research platform consists of a set of web services provided by a remote server (or cloud) and a definition of the data and procedures for accessing those services defined in an Interface Control Document (ICD) [4]. The ICD defines the communication between the UTM research platform and an operator. This allows operators to implement a client to interface their operational platform to UTM to exchange messages, information about flight plans, and constraints in the system. NASA tested this platform with several industry partners in August of 2015 at a single location [5]. To further exercise the system, a distributed test using the FAA Test Sites was devised and implemented. The FAA “selected six UAS test site operators that will allow the agency to develop research findings and operational experiences to help ensure the safe integration of UAS into the nation’s airspace” [6]. The distributed test using the Test Sites is the subject of the remainder of this paper. The next section describes the test plan, followed by an overview of the execution of the plan. The results are provided in Section IV and the paper concludes with a discussion of lessons learned and a summary.

II. NATIONAL CAMPAIGN PLAN

NASA contracted directly and individually with each of the six FAA Test Sites to perform flight activities in support of the UTM research platform. The high-level requirements for each Test Site, driven by the TCL 1 concept, were the same. Each site needed to provide personnel, airspace, and UAS platforms such that they could execute four simultaneous operations connected to the UTM research platform in concert with the other sites. The goal from NASA's perspective was to have twenty-four distinct platforms (four from each of the six Test Sites) operational and flying while connected to UTM during the same hour. Given uncertainty in weather and the potential for technical problems with any of the platforms on any given day, the minimum success criterion was to have sixteen distinct platforms and operations connected to UTM during the same hour. NASA Ames Research Center would host the Command Center and manage the flight test from that location.

NASA had qualitative and technical objectives for this flight test. Qualitatively, NASA wanted to expose the Test Sites to the UTM concept and research platform in order to obtain feedback from the Test Sites. Secondly, NASA wanted to understand the potential applicability of UTM for further use at the Test Sites. Technically, NASA wanted to load the research platform with several distributed clients and test the Live, Virtual, Constructive capabilities for simulating operations in UTM together with live traffic.

The Test Sites and NASA agreed to an operational window of April 19-21, 2016. During the week prior to this window, aviation weather forecast reports and input from the Test Sites led to selecting April 19, 2016 for the National Campaign flight date. The desired time window on that day needed to support operations simultaneously in Alaska and New York, so 9:00 AM PDT (8:00 AM in Alaska and 12:00 PM in New York) was selected for flying over three consecutive hours, with plans to increase the test complexity with each subsequent hour.

During the first hour each site would fly each of its four platforms connected to UTM. During the second hour, the sites would do the same, and the NASA team at Ames Research Center would also inject up to four simulated operations near each site. In the final hour, each site would fly as many sorties as possible amongst its four platforms as individual operations with UTM. NASA would again inject four simulated operations at each site and additional simulated operations would be provided by another organization (Simulyze) at a remote location into the same scenario.

Each Test Site had freedom to choose their platforms and their method of connecting to the UTM research platform with a UTM Client of their choice/implementation based on the provided ICD [4]. A description of the platforms and clients is provided in Table I.

The ranges were spread across the United States in seven states, one in each of the Test Site states, with the Virginia Test Site flying at two locations: one in Virginia and the other in Maryland. The ranges used are summarized in Figure 1 and Table II. Overall, this set of ranges offered geographically disparate locations to fly simultaneous operations. The weather and terrain varied between sites, with all of them having appropriate, safe conditions for flight.

TABLE I. THE VEHICLES AND UTM CLIENTS USED BY EACH TEST

Test Site	Vehicle Name	UTM Client
AK	Ptarmigan hexacopter (DJI S800)	Simulyze-Flight Control (SFC)
AK	Ptarmigan hexacopter (DJI S800)	SFC
AK	ING Ptarmigan	SFC
AK	Aeromao Aeromapper	SFC
ND	Altavian Nova F6500	Altavian
ND	Botlink ER-1	Botlink
ND	InSitu ScanEagle	SFC
ND	Sensurion Magpie	SFC
NV	Tarot 650 Quadcopter	University of Nevada, Reno (UNR)
NV	Helipal Storm AG Quadcopter	UNR
NV	3DR Solo	UNR
NV	3DR Solo	UNR
NY	Lockheed Martin Indago	NASA
NY	Lockheed Martin Indago	NASA
NY	Lockheed Martin Indago	NASA
NY	Lockheed Martin Indago	NASA
TX	3DR Solo	Lonestar
TX	3DR Solo	Lonestar
TX	AirRobot AR180	Lonestar
TX	Lancaster Hawkeye Mk-III	Lonestar
VA	UAV Solutions Talon 120LE	NASA
VA	UAV Solutions Phoenix 60	NASA
VA	DJI Inspire	Sunhillo ADS-B
VA	3DR Aero	NASA

TABLE II. DESCRIPTION OF THE FLIGHT RANGES.

Test Site	Range Location	Comments
AK	Fairbanks, AK Poker Flat Research Range	Class G up to 1200ft. Uninhabited river valley.
ND	Grand Forks, ND Flying S Test Site	Rural private property. Class G.
NV	Reno, NV Reno-Stead Airport	Airport, Class G up to 700ft. Potential light general aviation traffic.
NY	Rome, NY Griffiss International Airport (RME)	Class D airspace under jurisdiction of RME tower.
TX	Port Mansfield, TX Charles R. Johnson Airfield	Class G to 1200ft. Nearby national park.
VA	Bushwood Farm, MD Raley Farm	Private property.
VA	Blacksburg, VA Kentland Farm	Private property owned by Virginia Tech.



Fig. 1. Locations of the flight ranges.

During the flight testing, many of the Test Sites used the opportunity to exercise various UAS use cases of interest to them. These included mock surveying operations, search and rescue, and infrastructure monitoring. As the UTM research platform is agnostic to these use cases, NASA did not collect these data.

III. OVERVIEW OF EXECUTION

On the morning of April 19th, 2016, each Test Site connected to a telecon hosted by NASA. In addition to the telecon, there was an Internet-based videoconference that Test Sites could join. Some of the test ranges had more reliable Internet connections than phone connections and they exercised this Internet-based option. The entirety of the telecon and videoconference were recorded for archiving and reference. The telecon began 90 minutes prior to the start of flight. NASA stepped through various checks with each site to ensure readiness. Operations commenced at 9:00 AM PDT coordinated by the NASA Ames command center.

Each site, on successfully beginning flight for each of their four operations, announced that commencement over the telecon. NASA checked the UTM research platform to ensure that data were being received appropriately. Any troubleshooting could occur over the joint telecon line, with the line otherwise left clear for further announcements from the Test Sites on their operations. Upon completing an operation, the respective Test Site would announce that completion.

At the command center set up at NASA Ames Research Center, visualization tools displayed live data from each Test Site. This was achieved through the use of tools to interface with the UTM research platform that allowed for retrieval and visualization of the operational data. These tools were connected to a twelve-panel video wall for monitoring and visualization. Half of that display is shown in Figure 2, with one panel dedicated to each Test Site.



Fig. 2. Command center display.

Operations during the first hour went as planned as all six Test Sites each flew four distinct operations with data submitted to the UTM research platform. This first hour allowed NASA to declare mission success given the minimum success criterion being met: at least sixteen operations were in the air during the same hour across at least four Test Sites. The second hour also went as planned with the live operations occurring in parallel with simulated traffic generated by NASA Ames. The third hour was equally successful with several Test Sites able to execute multiple sorties as individual operations within UTM while both NASA Ames and Simulyze injected simulated traffic. Some data regarding all of these operations across the three-hour window are provided in the next section.

IV. DATA COLLECTED

In this section, summaries of the data related to the execution of the National Campaign are provided. Each subsection focuses on a different aspect of the collected data. First, overall operation statistics are provided. Next, data related to the position reports are examined. Finally, information about the various messages sent and received during the operations is discussed.

A few notes on how some anomalous data were treated prior to analysis are as follows. Some test operations performed prior to the 9:00 AM PDT start time by various sites were deleted from the system prior to analysis. Some position reports from one test site were off by one month, so that was corrected to ease analysis. A small number of positions (less than twenty) were submitted over a day into the future. Those were deleted to ease aggregate statistical analysis. A few operations were received from operators not participating in the National Campaign and were deleted. The remaining data were used for the analysis described below.

A. Operations

An “operation” in UTM terminology for TCL 1 is a single airspace reservation for a finite amount of time for a single vehicle. In the future this definition may change. Given this current definition, we recorded 224 distinct operations in the UTM research prototype for the three-hour period of the National Campaign. This included real and simulated operations, including those that did not submit position reports while active. The lack of position reports may indicate that the operation did not actually fly, or that the positions were just not submitted during flight. Excluding those operations that did not submit position reports, there were 102 real operations and

67 simulated operations, for a total 169. A breakdown of these 169 operations by time and type is provided in Figure 3.

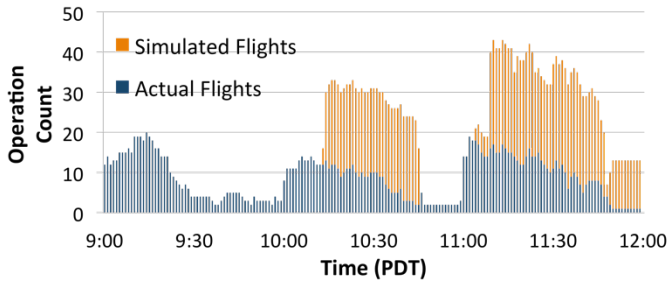


Fig. 3. Active operation count by minute

During the first hour there were no simulated flights and the maximum at any given minute was 20 simultaneous flights. During the second hour, simulated flights were launched after most of the real flights had begun during the 10:13 minute, causing the peak number of operations (real and simulated) to reach 33. The third hour introduced another simulation platform to inject operations and the various Test Sites flew multiple sorties asynchronously accounting for more variation in the operation counts. The peak number of operations during that hour was 43.

The UTM research platform is able to check that an operation's position reports occur within the region protected for that operation. Operations that submit positions outside their protected regions are said to be non-conforming. Figure 4 provides a sample from each Test Site that illustrates conforming operations. All maps presented are in a north up orientation. The red outline for each operation represents the protected area for that operation, while the green line indicates the originally submitted plan by the operation, note that this green line may appear very close to the red line depending on

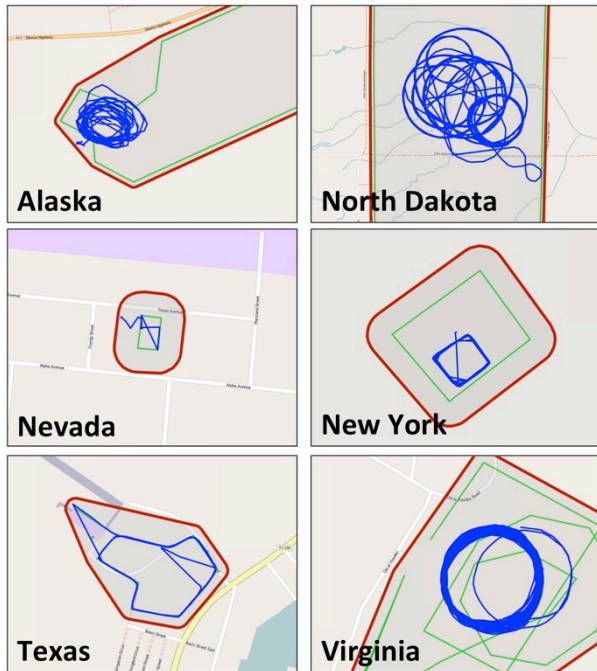


Fig. 4. Examples of conforming operations.

the zoom level of the image, but the distance is a minimum 100 feet between submitted and protected geographies. The blue line is the collection of position reports ordered into a line. Note that the cyan line remains inside of the protected area, thus implying operations that are conforming in terms of their position reports.

Figure 5 shows an example of a non-conforming operation for each Test Site. Again, these operations are non-conforming because at least one position report was received for the operation that was outside of its protected area.

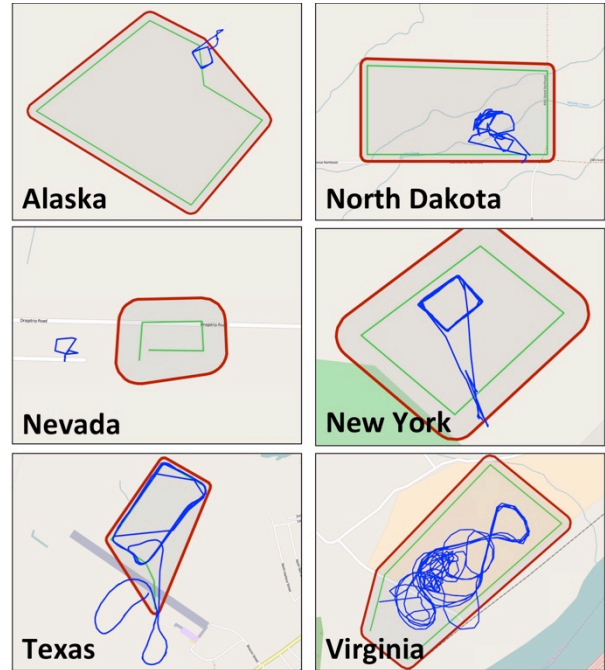


Fig. 5. Examples of non-conforming operations.

Overall there were 55 non-conforming operations. This is a high percentage of non-conformance (32.5% of all operations), which will be further discussed in the Lessons Learned section below.

Looking at the aggregate statistics, for the 102 real operations, there was a total of 112,440 seconds of position information provided to the UTM research platform, which translates to a maximum of 31 hours 14 minutes of flight time. This can be considered an upper bound estimate of the flight time captured by the platform since positions may have been reported while the vehicle was on the ground before and after the operation landed. This is a major increase of flight time under the UTM research platform as of the date of the National Campaign and represents a significant jump in the confidence for the NASA team that the research platform is able to provide common situational awareness of the operations using the system.

In terms of distance, the real flights reported positions that indicate a total of at least 281.8 nmi flown. Adding in the simulated tracks, at least 775.6 nmi were flown during the National Campaign. Note that this is a lower bound for a couple of reasons. First, the position reporting is only once per second, but is sometimes less depending on the UTM Client

implementation, so the resulting path is a linearized estimation of the actual flown path. Also, this calculation only considers horizontal distance, further reducing the true distance flown. In addition, there were three operations that submitted positions well outside their protected area, likely due to a GPS error. The entire distance flown calculation for these operations were excluded from analysis, further lowering the overall distance flown across all operations. In the next section, further details on the position reports are provided.

B. Positions

There were 115,994 position reports received by the UTM research platform over the course of the flight test from both real and simulated operations. Note that this number is nearly equal to the number of seconds flown (112,440). This is due to the guideline provided to all participants that position reports are provided at 1 Hz. Some submitted more frequently than others did, but the average of 1.03 Hz shows that the guideline was relatively well followed. Of these 115,994 position reports, 9,696 represented non-conforming positions across the aforementioned 55 non-conforming operations.

C. Messages

Messages are generated by operators and sent to the UTM research platform from the operator's UTM Client for a number of reasons. These include activating an operation, cancelling an operation, closing an operation, or to send a free text message to a manager of the UTM platform. Messages are also generated by the UTM research platform itself in reaction to several scenarios. Messages are sent to operators to notify when the state of their operation has changed (e.g. from "Proposed" to "Accepted" or "Activated" to "Closed"). Messages are also sent when non-conforming positions are detected. A total of 3,541 messages were handled by the UTM platform over the course of the National Campaign.

The system maintains records of when messages are received and sent. It is illustrative to look at the time it takes the system to receive a position report, check if it is non-conforming, then generate and send a message to the operator in the case that it is non-conforming. All of this occurs while the system continues its other functionalities. This measure provides some insight into the efficiency and general responsiveness of the system. For the 55 non-conforming operations, we examined the time it took to generate a non-conforming message to the operator upon receiving the first non-conforming position. The statistics, with an average time of 20.31ms, are provided in Table III.

TABLE III. TIME BETWEEN RECEIVING NON-CONFORMING POSITION AND GENERATING A WARNING MESSAGE.

Minimum time	Average time	Maximum time
2.73ms	20.31ms	122.42ms

Another check performed on position reports is to ensure that the timestamps seem reasonable. This check looks at the time the position report is received versus the supplied field from

the operator indicating when the position was measured. If the measured time is greater than the time it is received at the server, there is likely a clock synchronization problem on the UTM Client side wherein the client machine's clock is set ahead of the server's clock. In this case, the UTM research platform issues a message to the operator indicating the potential clock issue. This occurred 139 times over 31 distinct operations from 4 different Test Sites.

V. LESSONS LEARNED

In this section, a few of the key lessons learned throughout the planning, execution, and analysis of the National Campaign are discussed.

A. Ability to Execute

A major qualitative finding of this exercise was that the FAA UAS Test Sites could successfully coordinate and execute a distributed flight test. This has implications for potential future use of the Test Sites for demonstrations and flight tests. Planning and obtaining approvals for flight in today's environment is a difficult process (which is an advantage provided by a system like UTM), so being able to offload that effort to other organizations while maintaining control of the overall test is valuable to NASA and other research organizations. This flight test also provided the NASA UTM team experience in planning and executing such a demonstration from a central command center. This, again, will likely prove valuable in the near future of the NASA UTM effort.

B. System Stability

The load experienced by the UTM research platform during the National Campaign was unique in the research platform's existence. Multiple sites connecting from across the U.S. had not been performed prior to this test at this scale. The platform held up under the load without running out of computing or network resources. This provides some qualitative confidence that the system is being built in a reasonable manner.

C. Operator Education

The UTM project has noticed in previous flight tests that educating the flight crews on the proper use of the UTM platform is important. This importance was again born out in this test. While the UTM education level of the crews was much higher than in any previous test, there are still areas where we can improve on imparting the expectations of the system as they pertain to operations. One example is maintaining an operation within its protected area. If there is a chance based on the conditions in the field or the aircraft being used that a larger area is required to perform all possible maneuvers, then that larger area should be requested for that operation. In an operational version of the UTM platform, the incidence of non-conforming operations should be much lower than what was observed during the National Campaign. In some cases, non-conformance could not be helped as a common launch area was needed for all simultaneous operations at a location, and since the plans are not allowed overlap, those operations necessarily began outside their individual protected areas. This issue will be addressed

somewhat in the TCL 2 version of the platform, but it also reveals a potential use case that needs further investigation.

D. Improved UTM Client Checkout

The UTM research team has been gradually improving its mechanisms to ensure that UTM Client implementations meet the published specification. For example, through flight testing and data gathering, the discrepancies in data collection between various UAS platforms have led to explicit standardization of data elements required for submission to UTM. These data elements include position reports and altitude units, for example. This knowledge and experience lays the groundwork for potential requirements in a future operational system.

E. Time Synchronization

Given the various systems that are communicating across the Internet for UTM, a common time reference is important. It is a topic that was discussed, but not formalized for this test. A formal process or procedure for maintaining synchronized clocks (within some tolerance) will be important for future tests and the UTM concept as a whole.

F. Data Analysis

Given that at the core of the UTM research platform is a database with a known schema, much of the data analysis can be planned in advance. The necessary scripts can be developed with the test plans themselves to ease data analysis after the test and provide more rapid feedback to stakeholders. Many of the developed scripts for data analysis may actually be useful in real time as researchers monitor the platform during the flight test.

VI. SUMMARY

The National Campaign led by NASA to demonstrate UTM capabilities across a wide set of ranges simultaneously provided actionable insights into the current UTM research platform. During the three-hour flight test, the platform performed as designed and the FAA Test Sites operated all of the planned UAS flights while connected to the common platform hosted at NASA Ames Research Center. Over 100 UAS flew seamlessly with 67 simulated operations during the testing period. Data were shared amongst all stakeholders

through the research platform and the various interfaces built by the participants. Overall, this activity provided confidence that the work is progressing in the correct direction, exposed the Test Sites to the UTM concept in a hands-on manner, and opened the possibility for future tests organized in a similar manner as the UTM concept matures.

ACKNOWLEDGMENTS

There are many people and organizations that made this flight test a success. Parimal Kopardekar, manager for NASA's SASO project, initiated the UTM effort and established this activity with the Test Sites. Davis Hackenberg and Rosalia Toberman at Armstrong Flight Research Center handled the contracting mechanisms for the National Campaign. Lou Glaab from Langley Research Center and Frank Aguilera from Ames Research Center worked closely with the Test Sites to ensure their readiness for the flight test. The Test Sites themselves were invaluable through this process working with us to develop the goals and parameters of this flight test in a collaborative way and then executed flawlessly.

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